Preface

Mathematical modeling is the art of describing real-world phenomena in the terms of mathematical concepts. The increasing importance of mathematical modeling in solving economic–environmental problems is a relevant trend in modern research. Relations between human society and the environment are interdisciplinary and include technological, scientific, economic, biological, demographic, social, and political aspects. This textbook presents various mathematical models used in economics, ecology, and environmental sciences and discusses connections among them. Topics include economic growth and technological development, population dynamics and human impact on the environment, resource extraction and scarcity, air and water contamination, rational management of economy and the environment, climate change, and global dynamics. The authors focus on deterministic models and their investigation techniques, including discrete and continuous models, differential and integral equations, optimization and optimal control, and steady-state and bifurcation analyses.

This expository textbook offers an attractive collection of a wide range of models ranging from the classic Cobb–Douglas production function, Solow models of economic growth, Lotka–Volterra and McKendrick–McCamy population models, Hotelling and Dasgupta–Heal models of exhaustible resource, and Forrester and Meadows models of world dynamics to modern models of technological change and environmental protection that have so far appeared only in scientific journals. The authors demonstrate that the same models can be used to describe different economic and environmental processes and similar investigation methods are applicable to analyze various models.

The main goals of this textbook are:

- To expose modern practice of applied mathematical modeling in economics, population biology, and environmental sciences
- To describe relations among various economic, population, and environmental models
- To demonstrate how integrated mathematical models are built from simple components

- To explain investigation techniques for considered models and to provide an interpretation of the obtained results

This textbook is intended for graduate and upper-division undergraduate students, faculty, academics, and industry practitioners in economics and environmental sciences as well as for a wide mathematical audience. It also presents a self-contained introduction for researchers coming into the field for the first time.

Textbook Features

Since the publication of the first edition of this book by *Kluwer Academic* in 1999, the authors have been regularly contacted by universities from across the world about using it as a textbook. The first edition was republished in China in 2006 by *Science Press* as Volume 23 of their "Series of Mathematical Masterpieces Abroad" and translated entirely into Chinese by the *Renmin University of China Press* in 2011.

The second edition is entirely revised and updated compared to the first edition. Obsolete material has been replaced with new and more relevant models, references have been essentially updated, and exercises have been added to the end of every chapter. Solutions to all end-of-chapter exercises and other supplement materials are not included due to space constraints but will be available to instructors who adopt this textbook into their courses (contact the authors at nahritonenko@pvamu.edu or the publisher). The present edition has been classroom tested. The authors have successfully used its draft in teaching undergraduate and graduate courses in mathematical modeling at several universities in the United States, Europe, and Asia.

Most of the material is modular to allow for various course configurations, emphasizing certain economic, biological, or environmental applications. The authors strive to give an instructor substantial flexibility in designing a syllabus and using their preferred mathematical tools. The majority of chapters are relatively independent and can be covered in full or partially and in an arbitrary order. Some exceptions are the following:

- Chapter 2 and Sect. 3.1 are recommended for a better understanding of Chaps. 4, 5, and 10–12.
- Chapter 5 continues Chap. 4 and is mathematically more advanced.
- Chapter 7 can be covered after Chap. 6 and is more advanced.
- Chapter 9 can be covered after Chap. 8 and is more advanced.

To better understand a specific modeling problem, students need an integrated understanding of mathematical modeling. To address this need, the textbook explores a variety of diverse mathematical models from different applied areas and provides elements of their analysis, rather than merely focusing on a complete analysis of few problems. It includes theorems with occasional proofs where they are reasonable and effective. Special attention is given to the step-by-step construction of models, choice of control variables, analysis of arising mathematical problems and their interaction, qualitative behavior of model trajectories, and applied interpretation.

The set of considered economic–environmental models is representative enough to demonstrate how new problems and processes under study determine the choice of mathematical tools. The models of Chaps. 2, 3, 6, 10, and 11 use mostly ordinary differential equations, whereas Chaps. 7–9 consider partial differential equations and Chaps. 4 and 5 use integral equations.

This textbook explains how complex models are constructed from common simple modules that describe elementary economic and environmental processes. The economic models of Chaps. 2 and 3 are used as blocks in the models of Chaps. 4, 5, 10, 11, and 12. The models of resource extraction of Chap. 10 are used as blocks in the models of Chaps. 11 and 12. The models with environmental control of Chap. 11 and the world models of Chap. 12 consider population models of Chap. 4 and environmental pollution models of Chaps. 8 and 9 in an aggregated form.

Recommended Courses

The present edition is designed to serve as a textbook for one- and/or two-semester courses in mathematical modeling. The entire content of this textbook covers a two-semester graduate course in *Applied Mathematical Modeling* or *Mathematical Models and Methods*. In one-semester courses, some chapters and sections can be omitted without affecting the logical development of the material. Depending on the chapters chosen, this textbook can fit both undergraduate and graduate courses. Specifically, it can be used for several undergraduate courses in Departments of Mathematics, Environmental Sciences, Environmental Research, Ecosystem Science and Management, Management Sciences, Science and Technology, and so on. The table below lists some of the courses for which this textbook is recommended.

Sample course	Level	Content
Applied Mathematical Modeling	Undergraduate	Chaps. 1–4, 6, 10, 12
Mathematical Methods in Economics and Environment	Undergraduate	Chaps. 1–4, 8, 10, 11
Mathematical Modeling in Economics	Undergraduate	Chaps. 1–5, 10, 12
Models of Biological Systems	Undergraduate	Chaps. 1, 6, 7, 10, 12
Environmental Models	Undergraduate	Chaps. 1, 2, 6, 8–12
Applied Optimization Models	Undergraduate	Chaps. 1–7, 10, 11
Mathematical Models (for mathematics majors)	Undergraduate	Chaps. 1, 2, 4, 5, 6–10
Mathematical Modeling (for non-mathematics majors)	Undergraduate	Chaps. 1–3, 6, 10, 12
Applied Mathematical Modeling	Graduate	Chaps. 1–4, 6, 8, 10–12
Mathematical Models and Methods (two semesters)	Graduate	Chaps. 1–12

The presentation level requires mathematical knowledge of basic university mathematics courses, including *Calculus* and, ideally, *Differential Equations*. The authors avoid using advanced mathematical concepts or provide them as Appendices, e.g., in Chaps. 2 and 5.

Review of Textbook Content

Chapter 1 explores the steps of applied mathematical modeling and provides a brief overview of its concepts, notations, and tools. The remaining chapters are divided into three parts.

Part I "Mathematical Models in Economics" (Chaps. 2–5) is devoted to the mathematical modeling of economic systems. This area of modeling is well established with its own terminology, classification, and investigation methods. The considered models are used later in Part III as components in more sophisticated models of integrated systems. Chapters 2 and 3 analyze aggregate nonlinear economic–mathematical models based on production functions. Chapters 4 and 5 concentrate on the models of economic and technological development under improving technology, described by integral or partial differential equations. Part I focuses on the qualitative analysis and optimization in considered models. An appendix to Chap. 2 contains a review of extremum conditions (maximum principle) for the optimal control problems studied in this and subsequent chapters.

Part II "Models in Ecology and Environment" (Chaps. 6–9) explores various mathematical models used in population and environmental problems. It covers two large topics: models of biological communities and their rational exploitation (Chaps. 6 and 7) and models of pollution propagation in the atmosphere and water reservoirs (Chaps. 8 and 9). Some basic models of Chaps. 2–10 are only briefly discussed because they can be found in more specialized textbooks. However, more complex models constructed from these components are explained in detail.

Part III "Models of Economic–Environmental Systems" is devoted to integrated models of economic and environmental dynamics. Chapter 10 describes various models of nonrenewable resource extraction, including the well-known Hotelling's rule and Dasgupta–Heal model of economic growth with an exhaustible resource. Chapter 11 focuses on economics of climate change and explores aggregate optimization models of economic–environmental interactions such as pollution accumulation and abatement and adaptation to environmental damage. Chapter 12 offers a brief glance at the history and mathematical structure of famous models of global change, from the Club of Rome models to the modern integrated assessment models, their specifics, achievements, and limitations.

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